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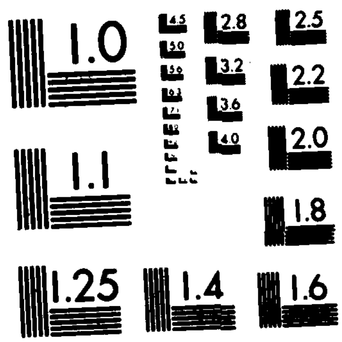

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WIND TUNNEL
DATA REPORT

SELECTION AND CALIBRATION OF PRESSURE TRANSDUCERS FOR LOW PRESSURE MEASUREMENT (0.001 psia) IN THE TUNNEL 9 HIGH ALTITUDE SIDE FORCE TESTS (~~WRT~~ WTR 1365)

BY

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STRATEGIC SYSTEMS DEPARTMENT

SEPTEMBER 1982

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A study of potential methods for measuring extremely low pressures (0.001 psia) in the NSWC Hypervelocity Wind Tunnel No. 9 was undertaken. Candidate techniques were evaluated in terms of compatibility with wind tunnel models, accuracy, response time, and availability. A detailed calibration was performed on random Microswitch, Model 130 PC transducers to check linearity, hysteresis, sensitivity, and repeatability. The effect of tube length and diameter on the response time of a pressure measuring system was also considered.

FOREWORD

A study of potential methods for measuring extremely low pressure (0.001 psia) in the NSWC Hypervelocity Wind Tunnel No. 9 was undertaken. Candidate techniques were evaluated in terms of compatibility with wind tunnel models, accuracy, response time, and availability. A detailed calibration was performed on random Microswitch, Model 130 PC transducers to check linearity, hysteresis, sensitivity, and repeatability. The effect of tube length and diameter on the response time of a pressure measuring system was also considered.

This work was performed in support of the FY82 High Altitude Side Force Test under the project leadership of Dr. C. Fiscina. The author wishes to thank all individuals involved for their participation in this task.

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INTRODUCTION

When simulating high altitude flight in the Hypervelocity Wind Tunnel #9, as in the FY 82 High Altitude Side Force Tests, accurate measurement of static pressure is difficult to obtain because of its low magnitude. For instance, at a supply pressure of 100 psi at Mach 14, the surface pressure on the leeward side of a sphere-cone model at high angle of attack is on the order of 50 μHg (0.001 psi). The limited run time of Tunnel 9 ($\approx$15 seconds) necessitates placement of transducers in the vicinity of the wind tunnel model for fast response while packaging constraints limit the type of transducers which can be used. In general, the smaller the full scale output of a pressure transducer, the larger the sensing element.

In choosing a transducer system for T-9, several factors were considered:

- transducer accuracy
- model compatibility
- response time
- test conditions
- cost
- availability

A discussion of these factors and how they led to the selection of Microswitch Model 130 PC transducers follows. Also, a detailed calibration of several random Microswitch transducers is shown in regard to linearity, repeatability, and response time.

PRESSURE SYSTEM CONSIDERATIONS

Due to the constraints of response time, physical size, and pressure range, many traditional techniques for measuring low pressure cannot be used in a short duration wind tunnel.[1] The McLeod gage and other mercury manometers measure micron-size pressures accurately, but are impractical because of their slow response time. Many diaphragm type gages are too large to be incorporated into a

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[1]Holman, J. P., "Experimental Methods for Engineers," McGraw-Hill, 1978, pp. 189-212.

wind tunnel model, particularly when multiple measurements are to be obtained. Mounting transducers outside of the wind tunnel would induce undesirable response time lag in the pressure tubing system. Other types of low pressure instrumentation, such as Bourdon tubes, don't have a broad enough range. From these constraints, it was decided to concentrate on diaphragm and piezoresistive type transducers.

The pressure transducer candidates for this study included:

- Microswitch, Model 130 PC
- Statham, Model PA208
- Setra, Model 239
- Validyne, Model AP-10
- Tavis, Model P4
- Rosemount, Model 1221F1VL

Rosemount, Tavis, and Validyne units were all larger than desired, but had good recommendations from previous users. The main drawbacks were cost and availability. Individual transducer unit costs, as high as $1600, were prohibitive since up to 24 individual pressure measurements were to be made. Also, procurement time had to be short to satisfy the High Altitude Side Force Test time constraints. The transducers from Microswitch, Statham, and Setra were compatible with the model, but past experience has shown that Setra transducers had zero-shift problems. The Statham transducers have position (gravity) sensitivity and add the extra complication of having to know each transducer's orientation. Of the final pressure transducer candidates, Microswitch best met the requirements of model compatibility, availability, and cost. Also, Microswitch transducers have been used successfully in the past at NSWC.[2] Bench test calibrations were accomplished for several random Microswitch transducers to verify their accuracy and response time over a range of pressures from 5 μHg (0.0001 psi) to 20,000 μHg (0.4 psi).

CALIBRATION

The Microswitch Model 130 PC is a solid state, piezoresistive pressure transducer with a 0.625 inch square base and height of 0.8125 inches. The sensing element is a 0.1 inch square silicon chip with a sensing diaphragm and four piezoresistors. When pressure is applied, the diaphragm flexes, changing the resistance. This results in an output voltage proportional to pressure. The model 130 PC is available in both an absolute type with a pressure range of 0-15 psi and a gage type with ranges of 0-5 psi and 0-15 psi. The absolute type gage was selected for the calibration due to its availability.

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[2]Harvey, D. W., Davis, J. C., and Prats, B. D., "Aerodynamics of Large Lateral Jets Emitted from Hypersonic Vehicles," AIAA 21st Aerospace Sciences Meeting, January 1983.

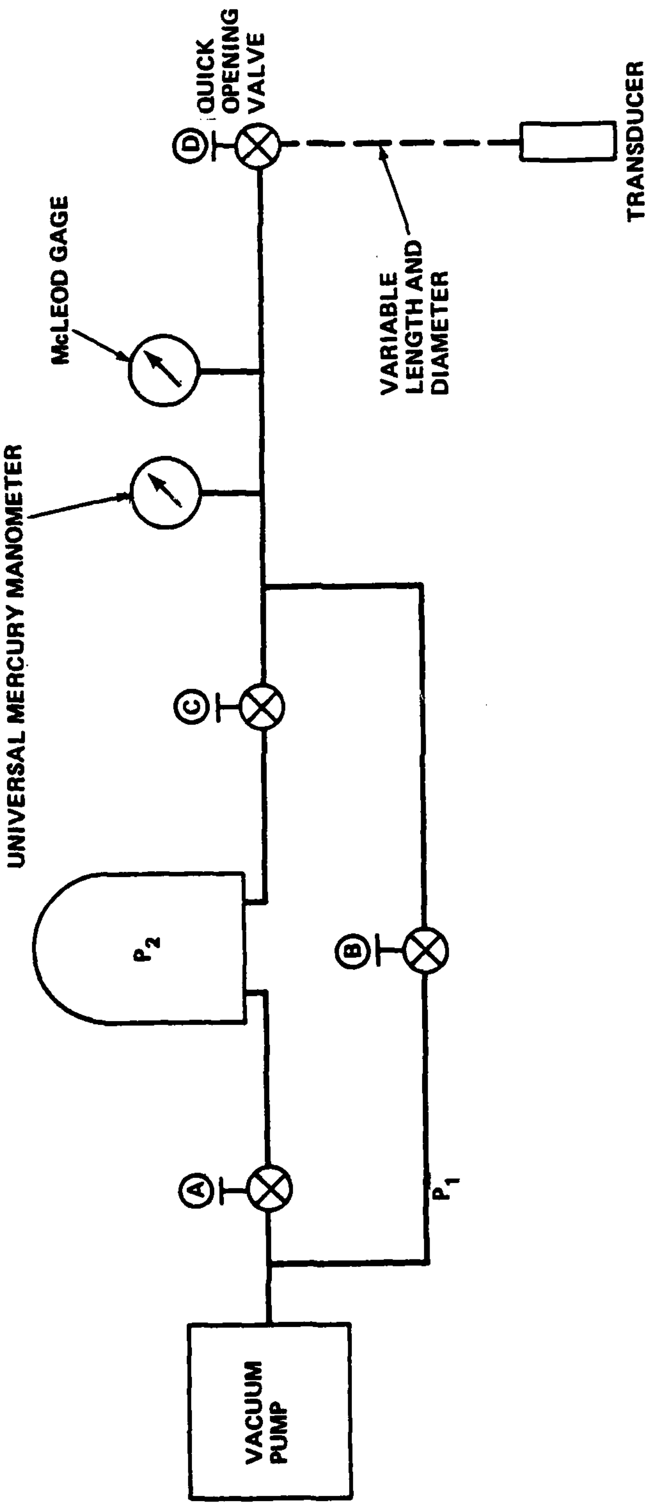

FIGURE 1. CALIBRATION SETUP

The calibration of the transducers consisted of three phases. In the first phase, random Microswitch transducers were checked for linearity and repeatability. In the second, response times of the transducers with various lengths and diameters of pressure tubing were experimentally measured. Third, the effect of noise and methods of filtering were checked. The calibration setup (Figure 1) utilized a vacuum pump, bell jar, and two pressure standards (a Universal mercury manometer and a McLeod gage). To check linearity, valves B and D were left open and the system was pumped down to discrete pressures. During the response time checks, an initial pressure, P_1, was isolated in the tube from valve D to the transducer. The pressure from the bell jar, P_2, was then bled into the system up to valve D and measured with the two pressure standards. Valve D was then opened and a trace of the transducer's response was recorded. Since response times in the low pressure range of interest are large ($\approx$ 1 second), the speed at which valve D opens is not critical.

The pressure range of greatest importance in this task was from 50 μHg (0.001 psi) to 3500 μHg (0.067 psi). Figure 2 shows the initial linearity check of a random Microswitch transducer versus data acquisition system counts (DARE counts). DARE counts is an artificial measurement of the transducer voltage output. During the calibration, the system was pumped down and measurements were taken. The system was then vented to atmospheric pressure and the procedure was repeated to assure no transducer hysteresis. A more detailed calibration at lower pressure (Figure 3) shows the good repeatability and linearity of this Microswitch transducer.

The Microswitch transducers are also linear over the range 50 μHg (0.001 psi) to 20,000 μHg (0.4 psi) (Figure 4). The impact of this fact is two-fold. First, a wide range of pressures can be measured accurately during one test. More importantly, an accurate calibration can be accomplished immediately prior to a wind tunnel run. Traditionally, an in-situ calibration of each transducer is performed prior to a run by taking discrete measurements as the wind tunnel is being evacuated. In certain cases however, the pressure to be measured during a test is lower than the lowest pressure attained during tunnel evacuation. For a low pressure case, an accurate calibration can be made down to the minimum evacuation pressure and the slope must be extrapolated to the low pressure range of interest. The extrapolation of the slope of a Microswitch transducer compared very favorably with test measurements (Figure 5).

Bench test results also showed that the response time of transducer/tubing systems was fast enough to allow multiple static measurements during the fifteen second run time (Figure 6). The response time lag is a function of the tube size. From Reference 3

$$t = \frac{16\,\mu \ell^2}{p_o d^2} \ln \frac{(p_o + p_t)(p_o - p_i)}{(p_o - p_t)(p_o + p_i)}$$

[3]Bauer, R. C., "A Method of Calculating the Response Time of Pressure Measuring Systems," AEDC TR 56-7, November 1956.

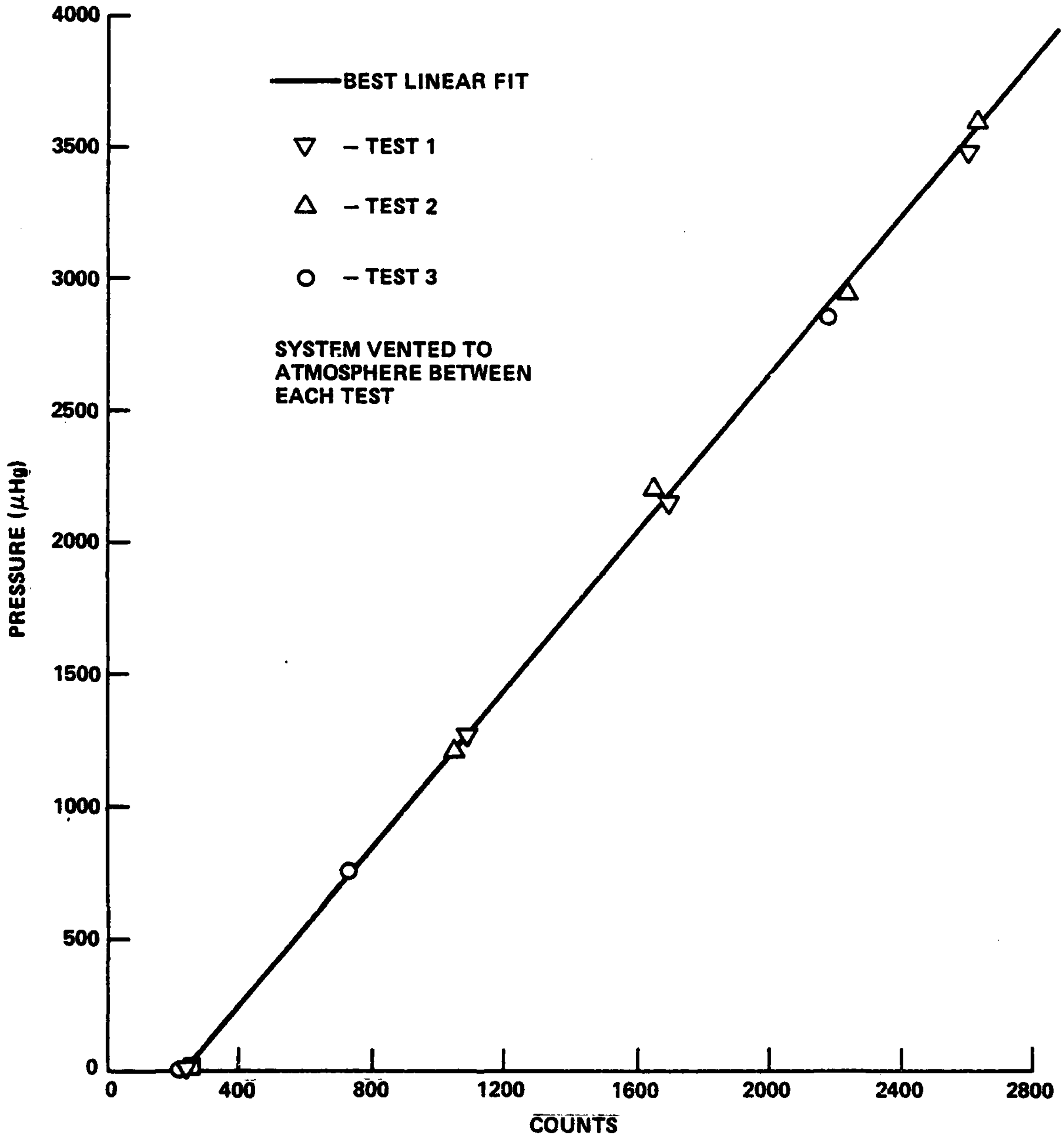

FIGURE 2. CALIBRATION: MICROSWITCH NO. 77 PRESSURE VS COUNTS

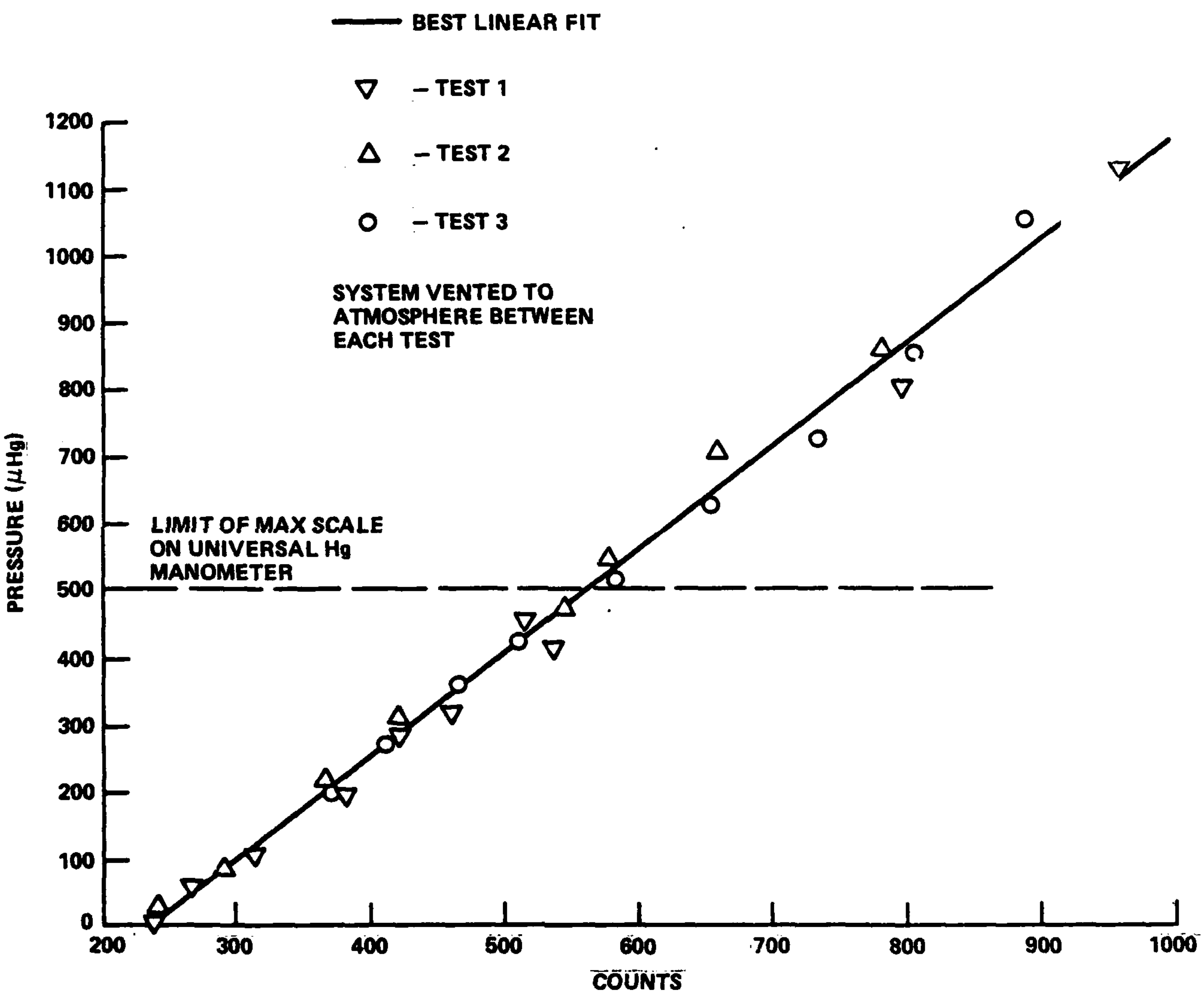

FIGURE 3. CALIBRATION: MICROSWITCH NO. 77 DETAILED CALIBRATION

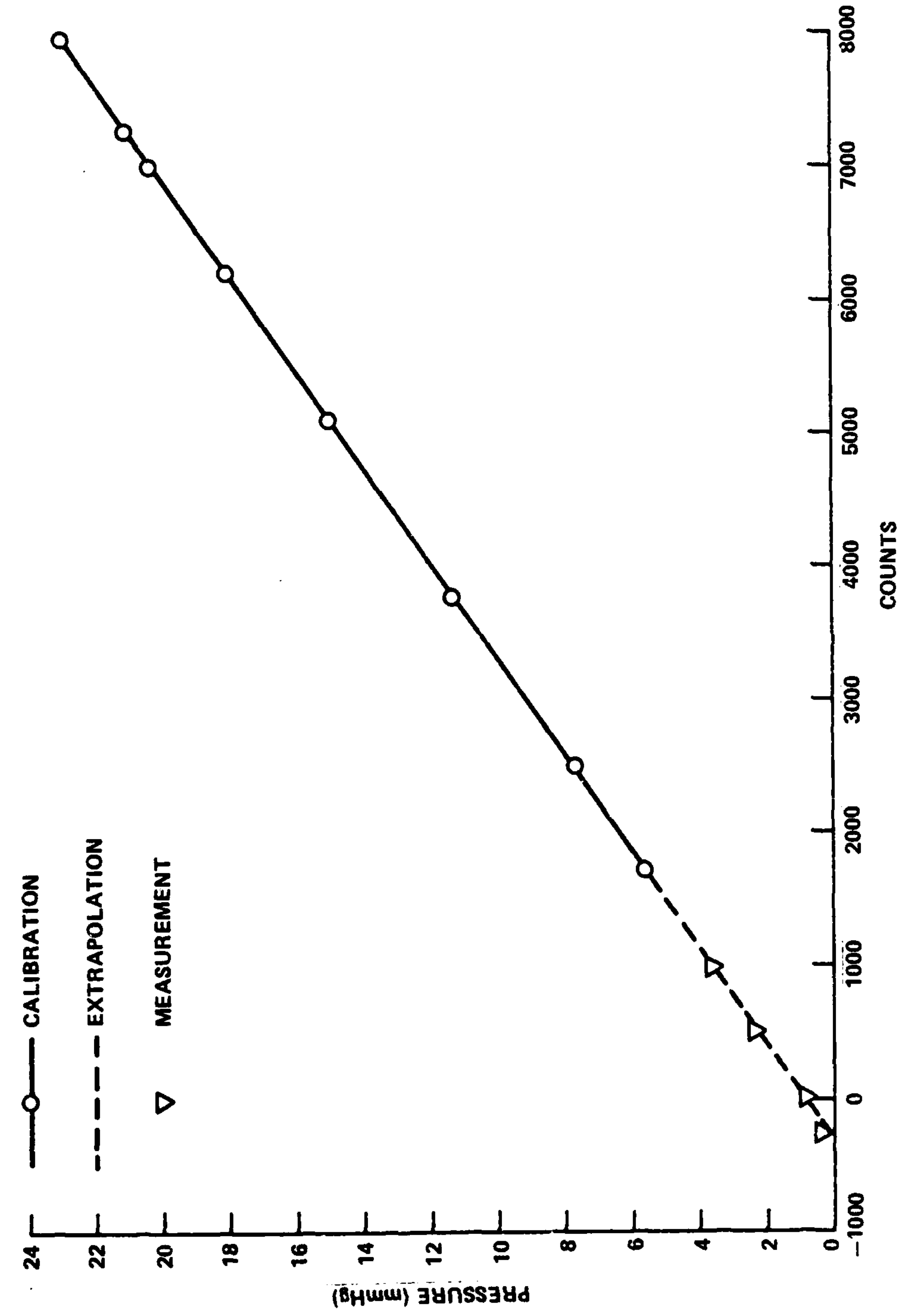

FIGURE 4. CALIBRATION: MICROSWITCH NO. 77 EXTENDED CALIBRATION

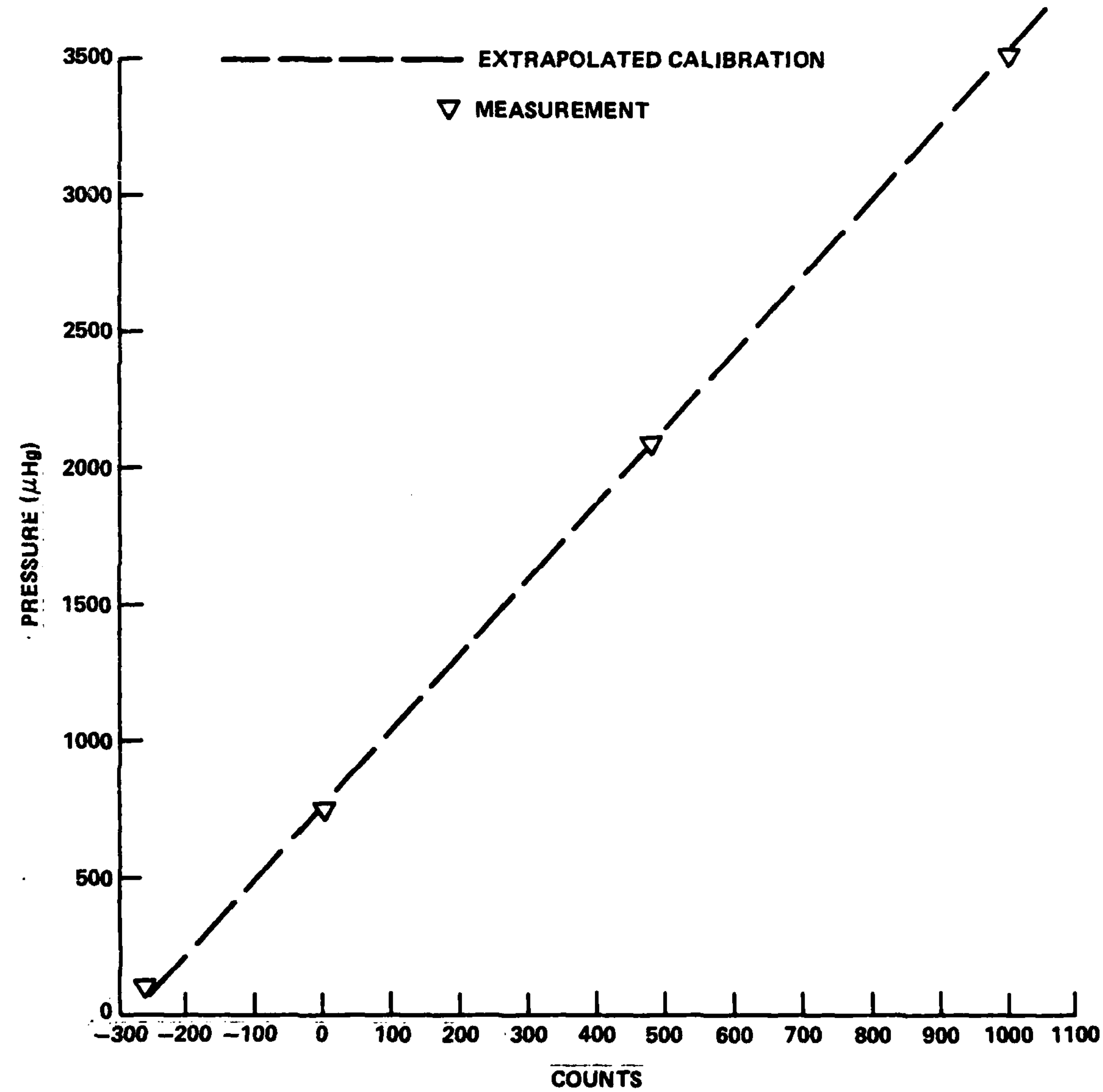

FIGURE 5. CALIBRATION: MICROSWITCH NO. 77 EXTRAPOLATED CALIBRATION

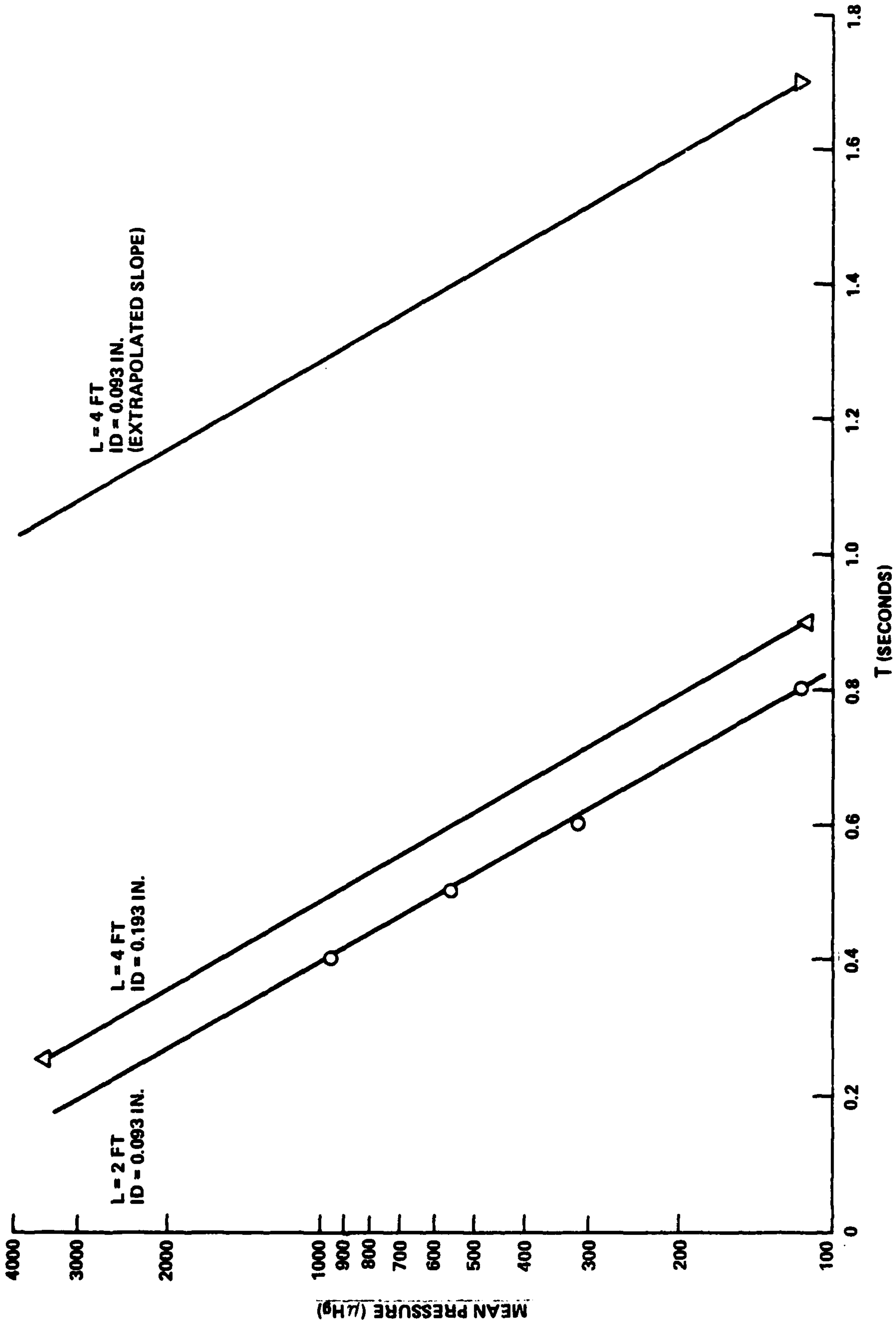

FIGURE 6. MEAN PRESSURE VS TIME CONSTANT

TABLE 1. TIME CONSTANT COMPARISON

P_i (μHg)	P_o(μHg)	ℓ(ft)	d(in)	t_{CALC}(sec)	t_{EXP}(sec)
5	1500	2	0.093	0.22	0.4
1500	5	2	0.093	0.30	0.5
20	500	2	0.093	0.40	0.6
5	180	2	0.093	1.10	0.8
5	180	4	0.093	4.50	1.7
5	3500	4	0.193	0.10	0.25
5	175	4	0.193	1.05	0.9

where

p_o = orifice pressure

p_t = 63.2% full scale response pressure

p_i = initial pressure

Table 1 shows a comparison of the empirical equation for response time (which assumes zero gage volume) with the experimentally determined response times. The calculated results are in reasonable agreement with experimental results, except for the low mean pressure case with 4 ft. length and 0.093 diameter. Initially, plastic tubing was used for the response time calibration. However, the results obtained with the plastic tubing were not repeatable and the transducer output appeared very noisy. These problems were eliminated by changing to solid tubing, which doesn't have detrimental outgassing effects.

With the solid tubing, the transducer output signal was very steady when 2 Hz analog filters were used. Without the filters, the output was quite noisy. Unfortunately, limitations in the Tunnel 9 data acquisition system prohibit the use of front end analog filters when multiplexing. Multiplexing is necessary whenever more than sixteen channels of output are desired. Digital filtering,[4] which has proven to be successful in the past, eliminates the need for front end filters which, in turn, allows multiplexing. Calibrations were done on five Microswitch transducers, with the output signals unfiltered. Digital filtering (5 Hz Butterworth) was applied during the data reduction and gave excellent results (Table 2).

SENSITIVITY AND ACCURACY

In this test, transducers were excited with seven volts during a run. The sensitivity of the Model 130 PC with seven volt excitation is 13 μHg (0.0003 psi) per DARE count. Standard deviations obtained during calibrations have been ± 3 DARE counts (± 39 μHg). Therefore, the uncertainty in the measurement of pressures in the 50 μHg range is high, but higher pressures, as on the windward side of a model, can be measured quite accurately.

[4]Hamming, R. W., Numerical Methods for Scientists and Engineers, McGraw-Hill, 1962.

TABLE 2. TRANSDUCER CALIBRATION DATA

TEST	PRESSURE STANDARD (psi)	TRANSDUCER PRESSURE (psi) T140	T137	T144	T139	T43
1	.5032	.5034	.5029	.5035	.5021	.5032
2	.3910	.3913	.3915	.3912	.3913	.3912
3	.3174	.3177	.3173	.3174	.3168	.3183
4	.2155	.2158	.2144	.2153	.2139	.2177
5	.1769	.1770	.1771	.1767	.1773	.1784
6	.1339	.1345	.1333	.1342	.1328	.1356
7	.0814	.0818	.0820	.0817	.0817	.0818
8	.0541	.0549	.0529	.0545	.0524	.0567
9	.0212	.0211	.0217	.0208	.0221	.0217
10	.0093	.0101	.0086	.0095	.0090	.0124

ORIFICE EFFECTS

When making pressure measurements in low-density conditions, the shear stress can cause the measured pressure to be significantly different from the force per unit area on the surface adjacent to the orifice. This is called the orifice effect.[5] Orifice effects must be considered when the orifice diameter is much less than the local mean free path. A sample calculation of mean free path is given in Appendix A for typical Tunnel 9 test conditions. Typically, orifice diameters can be made large enough so that orifice effects are negligible.

CONCLUSION

From the detailed calibrations, the Microswitch Model 130 PC transducers are linear, repeatable, and with solid tubing have adequate response times to allow multiple static measurements during a Tunnel 9 run. They also have the advantages of being compatible with wind tunnel models, readily available, low in cost, and have been used successfully in the past. Over the range of pressures to be measured during a wind tunnel test, the Microswitch transducer is sensitive and accurate. Of the previously identified measurement technique candidates, the Microswitch transducers are best suited for measuring low pressures in short duration wind tunnels such as Tunnel 9.

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[5]Kinslow, M., and Potter, J. L., "Reevaluation of Parameters Relative to the Orifice Effect," 7th Symposium on Rarefied Gas Dynamics, Academic Press, New York, 1970.

REFERENCES

1. Holman, J. P., "Experimental Methods for Engineers," McGraw-Hill, 1978, pp. 189-212.

2. Harvey, D. W., Davis, J. C., and Prats, B. D., "Aerodynamics of Large Lateral Jets Emitted from Hypersonic Vehicles," AIAA 21st Aerospace Sciences Meeting, January 1983.

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4. Hamming, R. W., Numerical Methods for Scientists and Engineers, McGraw-Hill, 1962.

5. Kinslow, M., and Potter, J. L., "Reevaluation of Parameters Relative to the Orifice Effect," 7th Symposium on Rarefied Gas Dynamics, Academic Press, New York, 1970.

6. Yanta, W. J., "A Hot-Wire Stagnation Temperature Probe," NOLTR 68-60, June 1968.

NOMENCLATURE

d	Tube diameter
ID	Tube inside diameter
ℓ	Tube length
P_i	Initial pressure
P_o	Orifice pressure
P_t	63.2% full scale response pressure
P_1	Initial line pressure
P_2	Bell jar pressure
R	Universal gas constant
T	Static temperature
T_o	Stagnation temperature
γ	Ratio of specific heats
λ	Mean free path
μ	Coefficient of viscosity
μHg	Microns of mercury
t	Time constants

APPENDIX A

CALCULATION OF MEAN FREE PATH

Reference 6:

$$\lambda = 1.06 \frac{\mu}{p} \sqrt{\gamma RT}$$

λ = Mean free path

$$\mu = \text{Viscosity} = 3.7 \times 10^{-7} \frac{lb_f \ sec}{ft^2}$$

$$\gamma = 1.4$$

$$R = 55.15 \frac{lb_f \ ft}{lb_m \ {}^\circ R}$$

$$g_c = 32.2 \frac{lb_m \ ft}{lb_f sec^2}$$

$$P_{min} = \text{Minimum pressure} = 50 \ \mu Hg = 0.144 \frac{lb_f}{ft^2}$$

$$T_o = 3000^\circ R \ @ \ M = 13$$

$$\left.\frac{T}{T_o}\right|_{M=13} = 0.0287 \Rightarrow T_1 \cong 86^\circ R$$

$$\left.\frac{T_2}{T_1}\right|_{M_{1_n} = 3.3} \cong 3 \Rightarrow T_2 \cong 260^\circ R$$

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[6]Yanta, W. J., "A Hot-Wire Stagnation Temperature Probe," NOLTR 68-60, June 1968.

$$\lambda = 1.06 \; \frac{\left(3.7 \times 10^{-7} \; \frac{lb_f sec}{ft^2}\right)}{0.144 \; \frac{lb_f}{ft^2}} \sqrt{(1.4)\left(32.2 \; \frac{lb_m ft}{lb_f sec^2}\right)\left(55.15 \; \frac{lb_f ft}{lb_m {}^\circ R}\right)(260^\circ R)}$$

$\lambda \cong 0.0022 \text{ ft} = 0.026 \text{ in.}$

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